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2.	Patent application number *(The Patent Office will fill in this part)*	08 JUL 2002 0215767.5
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Harman International Industries Limited 4th Floor Windsor House Pepper Street Chester CH1 1DF
	06924625004 Patents ADP number *(if you know it)*	
	If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4.	Title of the invention	Coated Loudspeaker Diaphragm
5.	Name of your agent *(if you have one)*	BOULT WADE TENNANT
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	VERULAM GARDENS 70 GRAY'S INN ROAD LONDON WC1X 8BT
	Patents ADP number *(if you know it)*	42001

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Country	Priority application number (if you know it)	Date of filing *(day/month/year)*

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Adrian C. Hayes
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Coated Loudspeaker Diaphragm

Field of the invention

The present invention relates to a loudspeaker diaphragm.

Background of the invention

Loudspeaker diaphragms, and in particular loudspeaker cones, have characteristic resonances, which are determined by the dimension, stiffness and density of the diaphragm. These characteristic resonances have the effect of making the sounds emitted by the loudspeaker harsh, at the frequencies at which these resonances occur.

Aluminium has been used for the manufacture of loudspeaker cones for a number of years. An aluminium cone itself, however, tends to have characteristic resonances within the audible frequency range. Thus, the sounds emitted by the loudspeaker cone at these characteristic resonant frequencies are harsh. This has a negative effect on the acoustic performance of the cone.

To ameliorate this problem, an anodically formed oxide layer is often applied to the aluminium surface. This increase in the stiffness of cone structure, results in an increase in the characteristic resonance frequencies of the cone within the audible frequency range, thus extending the usable bandwidth of the loudspeaker. The frequency response curve is also flattened. As a consequence, the acoustic performance of the cone is improved. Typically, the

anodically formed oxide layer is formed on both sides of the aluminium cone.

Anodising, however, can have a negative effect on the strength of the cone. This is because metal is consumed from the surface during the anodising process, resulting in a thinner, and consequently, weaker structure. Conventionally, this problem is addressed by using a thicker aluminium substrate. This, however, has the effect of increasing the overall mass of the cone, and can have an adverse effect on the acoustic performance.

Summary of the invention

According to the present invention, there is provided a loudspeaker diaphragm comprising a first region and a second region, said diaphragm having a coating on at least part of at least one major surface of said first region and an optional coating on at least part of at least one major surface of said second region, wherein at least part of the coating on said first region is thicker than at least part of the optional coating on said second region of the diaphragm.

In this application, the term "diaphragm" is intended to cover loudspeaker diaphragms of any shape, including loudspeaker cones.

The first region of the diaphragm may be arranged radially outside of the second region of the diaphragm. Preferably, the second region is adjacent the first region. For example, in the case of a loudspeaker cone, the first region of the

diaphragm may cover the conical region of the cone, and the second region of the loudspeaker cone may cover the cylindrical region of the cone.

Brief description of the Figures

Figure 1 is a cross-sectional view of a loudspeaker,

Figure 2 depicts the loudspeaker diaphragm of Figure 1 in greater detail,

Figure 3 depicts a loudspeaker diaphragm comprising a first region and a second region, wherein each region has a coating of uniform thickness, and wherein the coating on the first region is thinner than the coating on the second region,

Figure 4 depicts a loudspeaker diaphragm comprising a coating that is tapered in cross-section,

Figure 5 depicts an alternative loudspeaker diaphragm to that depicted in Figure 3, in which the dome is attached to the voice coil former,

Figure 6a depicts a loudspeaker diaphragm comprising a coating having a first region that is uniform in cross-section, and a second region that is tapered in cross-section,

Figure 6b depicts a loudspeaker diaphragm comprising an alternative coating to the coating shown in Figure 6a,

Figure 7 depicts a loudspeaker diaphragm having a thin, uniform coating on the cylindrical region of the diaphragm, and a thick, uniform coating on the conical region of the diaphragm,

Figure 8 depicts a loudspeaker diaphragm having a coating on both the inner surface and outer surface of the diaphragm,

Figure 9 depicts a loudspeaker diaphragm having a coating on both the inner surface and outer surface of the diaphragm, wherein only the coating on the inner surface of the diaphragm is thinner in the cylindrical region of the diaphragm than in the conical region of the diaphragm,

Figure 10 is a schematic view of an electrochemical cell, which may be employed to produce a loudspeaker diaphragm in accordance with the present invention,

Figure 11 is a schematic view of an arrangement that may be employed to mask an anodisable substrate,

Figure 12 is a schematic view of an alternative arrangement to that depicted in Figure 11,

Figure 13 is a schematic view of an electrochemical cell, which may be employed to produce a loudspeaker diaphragm in accordance with the present invention, and

Figure 14 is a schematic diagram of a section of a loudspeaker diaphragm anodised using the apparatus of Figure 13.

Detailed description of the invention

One aspect of the present invention relates to improved loudspeakers.

A suitable loudspeaker is illustrated in Figure 1. As can be seen from the drawing, the loudspeaker comprises a loudspeaker diaphragm, a dome 2, and a voice coil 3. The voice coil 3 comprises a voice coil former 3a and voice coil windings 3b. The loudspeaker diaphragm is held within a chassis 4 by a suspension system provided by a surround 5 and spider 6.

The loudspeaker diaphragm is illustrated by way of example, as a loudspeaker cone 1. The cone 1 comprises a generally cylindrical region 7, and a generally conical region 8. The voice coil former 3a is attached to the cylindrical region 7, and held in place using an adhesive. The dome 2 is positioned within the conical region 8 of the cone 1, and is bonded to the cone 1 using an adhesive. In an alternative arrangement (not shown), the dome 2 may be attached to the voice coil former 3a.

The voice coil windings 3b are positioned within a magnetic field provided by the magnetic system 9. Thus, when an alternating current is passed through the voice coil windings 3b, the voice coil 3 moves back and forth in the magnetic field. This causes the loudspeaker cone 1 to vibrate at the frequency of the alternating current, and to emit sounds. The surround 5 and spider 6 allow the loudspeaker cone 1 to move in positive and negative

directions within a finite excursion over a limited frequency range.

The region of the diaphragm that is primarily responsible for the sound emitted by the loudspeaker is generally known as the acoustic region of the diaphragm. Typically, this region is located in the conical region 8 of the diaphragm, for example, between the point of attachment of the dome 2 and the periphery of the diaphragm. In cases where the dome 2 is attached to the voice coil former 3a, the acoustic region may extend across the entire area of the conical region 8 of the diaphragm.

Figure 2 depicts the loudspeaker diaphragm of Figure 1 in greater detail. As with Figure 1, this diaphragm is illustrated by way of example, as a loudspeaker cone 1. At least part of the conical region 8 of the cone 1 may be provided with a coating. Optionally, at least part of the cylindrical region 7 of the cone 1 may be provided with a coating.

The coating is intended to improve the acoustic performance of the diaphragm. For example, when the diaphragm is made from aluminium, an oxide layer may be formed on the diaphragm's surface to shift the diaphragm's characteristic resonances upwards in frequency. This, in some cases coupled with a general flattening of the diaphragm's frequency response curve, is aimed at improving the acoustic performance of the diaphragm.

The coating may be formed of any suitable material such as carbide, boride, nitride or oxide. Preferably, the coating

is formed of an oxide. More preferably, the coating is an anodically formed oxide layer. The coating may be formed by an anodic oxidation process, such as anodising. Alternatively, the coating may be formed by the Keronite process. The latter may be especially suitable for coating substrates formed of magnesium, titanium or alloys containing one or both of these metals.

The cylindrical region of the cone of Figure 2 is the region of the cone to which the voice coil, or more specifically, the voice coil former, may be attached. This region is sometimes known as the "neck" region of the cone. The coating may be absent from at least a part of the cylindrical region of the cone. Preferably, however, this cylindrical region of the cone is provided with a coating. For example, where the cone is formed of an anodisable material, the cylindrical region of the cone may be provided with a coating formed of an oxide layer, preferably, an anodically formed oxide layer, which enables a strong bond to be formed between the voice coil and the cylindrical region of the cone, for example, using an adhesive. The thickness of the coating in this cylindrical region, however, may be thinner relative to at least part, if not all of the coating in the conical region of the cone, for example, between the point of attachment of the dome and the periphery of the cone.

Figure 3 illustrates (by way of example) a loudspeaker diaphragm in which the dome 2 is attached directly to a conical diaphragm 1. The region 8a of the diaphragm 1 between point 8b, and the point 8c of attachment of the dome 2 may also be provided with at least a partial coating.

Coating the diaphragm relatively thinly in this region can help to improve the resistance of the coating to laminar fracture. The thickness of the coating in this region 8a may be thinner than at least part, if not all of the coating extending from the point 8c of attachment of the dome 2 to the periphery 8d of the diaphragm. For example, the thickness of the coating in region 8a may be substantially the same as the thickness of the coating in the cylindrical region 7 of the diaphragm 1. Alternatively, the coating may be tapered from a minimum thickness in the cylindrical region 7 of the diaphragm 1 to a greater thickness at the point of attachment of the dome 2. This taper may continue to a maximum value towards the periphery 8d of the diaphragm 1 (see Figure 4).

The coating in the conical region 8 of the diaphragm 1 may extend across the entire or part of the conical region 8 of the diaphragm 1. For example, the coating may cover at least part of the region between the point 8c of attachment of the dome 2 and the periphery 8d of the diaphragm 1 (see Figure 3). Preferably, the whole of this region is coated.

Generally, the coating extends across at least part of the acoustic region of the diaphragm. As described above, this is the region of the diaphragm that is primarily responsible for the sound emitted by the loudspeaker. In the case of a loudspeaker diaphragm having a conventional shape, the acoustic region is generally but not exclusively located in the conical region of the diaphragm, for example, between the point of attachment of the dome and the periphery of the diaphragm. In cases where the dome is attached to the voice

coil former, the acoustic region may extend across the entire area of the conical region of the diaphragm.

Preferably, the entire acoustic region of the diaphragm is coated. As described above, the coating is aimed at improving the acoustic properties of the diaphragm. Since it is the acoustic region of the diaphragm that is primarily responsible for the sound emitted by the loudspeaker diaphragm, it is in many cases desirable for this acoustic region of the diaphragm to be at least partially coated.

Figure 5 illustrates a loudspeaker diaphragm 1 in which the dome 2 is attached to the voice coil former 3. The coating on the conical region 8 of the diaphragm 1 may cover at least part of the conical region 8 (i.e. between point 8b and the periphery 8d of the diaphragm 1). Again, however, it is preferable for the coating to cover substantially the whole of the conical region 8.

As mentioned above, at least part of the coating on the conical region 8 is thicker than at least part of the optional coating 7a on the cylindrical region 7 of the diaphragm 1. Where the cylindrical region is coated, the entire coating on the conical region 8 may be thicker than the entire coating 7a on the cylindrical region 7 of the diaphragm 1.

The thickness of the coating in the cylindrical region of the diaphragm may be 0.1 to 8 microns, preferably, 1 to 4 microns, for example, about 2 to 3 microns. The thickness of the coating in the conical region of the diaphragm may be 2

to 50 microns, preferably, 8 to 40 microns, for example, about 10 to 20 microns.

The thickness of the coating may be determined by any suitable method; that selection will be influenced by the purpose of the particular measurement. Preferably, the thickness is measured over an average area of 0.01 to 1 cm^2, more preferably, 0.1 to 0.8 cm^2, most preferably, 0.2 to 0.5 cm^2, for example, 0.25 cm^2.

For example, to determine the average thickness of the coating over the entire surface of the diaphragm, the diaphragm is weighed and then stripped of the coating. Any suitable method may be employed to strip the diaphragm: for example, an acid, such as phosphoric and/or chromic acid may be employed to strip the diaphragm, in accordance with British DEF STAN 03-25. The stripped diaphragm is then weighed. The difference between the weight of the coated diaphragm and the stripped diaphragm is then that of the coating. The total surface area of the diaphragm is then calculated. Provided the density of the coating (e.g. aluminium oxide) is known, it is possible to calculate the average thickness of the coating.

Alternatively, the thickness at any particular part of the diaphragm may be established by measuring the overall thickness of the coated diaphragm using a micrometer. The diaphragm may then be stripped using any suitable method (e.g. British DEF STAN 03-25). The thickness of the stripped diaphragm is then measured. The difference between the two thickness measurements is the total thickness of the coating. Thus, if the diaphragm is coated on both its inner

and outer surface, the difference corresponds to the total thickness of the inner and outer coating. If it can be assumed that both coatings are equal in thickness, the difference between the thickness of the coated and uncoated diaphragm can be halved to give the thickness of each coating. However, if it is necessary to establish the coating thickness on the one surface of the diaphragm without reference to the other, the surface not to be measured may be protected from the stripping solution by a suitable masking technique, such a stopping-off lacquer or protective tape, so that the difference in micrometer readings is that of the required coating.

Other methods of measuring coating thickness include (not exclusively) use of eddy-current devices, calibrated microscope focussing successively on the anodised surface and that of the underlying metal. It should be noted that some methods might not be applicable in certain circumstances.

The coating may be tapered, for example, from a minimum value in the cylindrical region of the diaphragm, to a maximum value in the conical region of the diaphragm (e.g. at the periphery of the diaphragm). The taper may extend from a minimum value in the cylindrical region of the diaphragm to the outer edge of the conical region of the diaphragm. As shown in Figure 4, the coating on the cylindrical region 7 may itself be tapered. Alternatively, as shown in Figures 6a and 6b, the coating on the cylindrical region 7 may be substantially uniform in thickness. As shown in Figure 6a, the coating on the conical region 8 of the diaphragm 1 may taper from a minimum

value at point 8b to a maximum value at the periphery 8d of the diaphragm 1. Where the dome 2 is attached directly to the diaphragm 1 (see Figure 6b), the coating may be substantially uniform in the cylindrical region 7 up to the point 8c of attachment of the dome 2. From the point 8c of attachment of the dome 2, the coating may taper to a maximum value at the periphery 8d of the diaphragm 1.

The minimum thickness of the coating may be 4 to 25 % of the maximum thickness of the coating. Preferably, the coating is 1 to 3 microns thick in the cylindrical region of the diaphragm, and 9 to 11 microns thick at the periphery of the diaphragm. It should be noted that the angle of taper is dependent upon the size and profile of the diaphragm. Thus, the angle of taper will be different for different size diaphragms.

The diaphragm may be provided with a coating that has a first region of substantially uniform thickness, and a second region of substantially uniform thickness. The thickness of the first region is less than that of the second region. Thus, as shown in Figure 7, the first region "A" of the coating may extend across at least part of the cylindrical region 7 of the diaphragm 1, and the second region "B" may extend across at least part of the conical region 8 of the diaphragm 1. The first region of the coating may extend across substantially the whole of the cylindrical region of the diaphragm, and the second region extends across substantially the whole of the conical region of the diaphragm.

Where the dome 2 is attached to the voice coil former 3 as shown in Figure 5, the first region of the coating covers the region 7a in which the voice coil former 3 is attached, and the second region of the coating extends from point 8b to the periphery 8d of the diaphragm 1. Where the dome 2 is attached to the diaphragm 1 as shown in Figure 3, the first region of the coating may cover the cylindrical region 7 of the diaphragm 1 up to the point 8c of attachment of the dome 2. The second region of the coating may extend from the point 8c of attachment of the dome 2 to the periphery 8d of the diaphragm 1.

The thickness of the coating in the first region may be 0.1 to 8 microns, preferably, 1 to 4 microns, for example, 2 microns. The thickness of the coating in the second region may be 2 to 50 microns, preferably, 8 to 40 microns, for example, 10 to 20 microns.

The thickness of the coating may be determined by any of the methods described above.

The diaphragm may be formed of any suitable material, preferably, an anodisable material, such as aluminium, titanium, magnesium and/or alloys of one or more of aluminium, titanium, magnesium. Preferably, aluminium is employed. The diaphragm may be formed using any suitable method for producing loudspeaker diaphragms. For example, pressing and/or spinning techniques may be employed.

The diaphragm may be coated, for example, by anodising both sides of the diaphragm. As shown in Figure 8, each coating layer may be thinner at the cylindrical region 7 of the

diaphragm than in the conical region 8 of the diaphragm 1. Alternatively, as shown in Figure 9, only one of the coating layers may be thinner at the cylindrical region 7 of the diaphragm 1 than in the conical region 8 of the diaphragm 1. This coating layer is preferably located on the inner surface of the diaphragm 1 (i.e. the surface of the diaphragm to which the dome may be attached). The coating on the outer surface of the diaphragm 1 may be substantially uniform in thickness.

As shown in Figure 7, only one side of the diaphragm 1 may be coated. Preferably, only the inner surface of the diaphragm is coated, for example, with an oxide layer. The outer surface of the diaphragm 1 may be left uncoated.

For the avoidance of doubt, the inner surface of the diaphragm is the surface of the diaphragm to which the dome and/or voice coil former is typically attached and which typically faces the listener. The outer surface of the diaphragm is the opposite surface of the diaphragm to which, for example, the spider (see Figure 1) is typically connected.

The diaphragm may be of a uniform thickness prior to coating. The coating process, however, may cause the diaphragm substrate to become non-uniform in thickness. For example, when a metal (e.g. aluminium) diaphragm is anodised, some of the metal at the surface of the diaphragm is consumed to form the anodically formed oxide layer. As a result, the diaphragm substrate becomes thinner in the regions where the anodically formed oxide layer is applied. Typically, the thicker the anodically formed oxide layer,

the more surface metal is consumed. The loudspeaker diaphragm may be provided with a tapered anodically formed oxide layer. Thus, the diaphragm substrate may be correspondingly tapered (see Figure 14).

Alternatively, the diaphragm may not be of a uniform thickness prior to coating. For example, some parts of the uncoated diaphragm (e.g. cylindrical region) may be thinner than other parts, as a result of the processing steps employed to produce the diaphragm.

The diaphragm described above may be incorporated into any suitable loudspeaker. Suitable loudspeakers include: sub woofers, bass, and midrange loudspeakers. The diaphragm described above may also be suitable for use in loudspeakers for automobile applications.

According to a further aspect of the present invention, there is provided a method for producing a diaphragm for a loudspeaker, such as the diaphragm described above.

This method may comprise applying a coating to a substrate, such that the thickness of at least part of the coating in the cylindrical region of the diaphragm is thinner than at least part of the coating in the conical region of the diaphragm.

The method may also comprise applying a coating to at least part of the conical region of the diaphragm, leaving the cylindrical region of the diaphragm substantially uncoated.

Any suitable coating technique may be employed to apply the coating to the diaphragm. Preferably, the coating is applied by an anodic oxidation process, such as anodising. Alternatively, the Keronite process may be employed.

The diaphragm may be employed as or connected to the anode of an anodising cell. The cathode may be formed of aluminium, lead, or stainless steel, and both electrodes are placed in a suitable electrolyte, such as sulphuric acid, chromic acid, oxalic acid, sulphosalysilic acid, or phosphoric acid. Of these electrolytes, sulphuric acid is preferred for which the concentration of the electrolyte may be 200 - 400g/l. For example, when sulphuric acid is employed as the electrolyte, the electrolyte concentration may be 200 to 300g/l sulphuric acid and 10 to 20g/l aluminium.

To commence the anodising process, a current is passed through the anodising cell. A current density of 0.5 to 3.0 Amps per square decimetre, preferably, 1 to 2 Amps per square decimetre of current density is preferably applied on the anode (work piece) surface. By passing a current through the cell in this manner, a layer of aluminium oxide is formed on the surface of the anode (work piece).

The anodising reaction may be carried out at a temperature of 0 to 35 degrees C, preferably, 20 to 30 degrees C.

To ensure that the anodised coating is thinner in the cylindrical region of the diaphragm, the anodising process may be carried out on the substrate until the anodised layer in the cylindrical region reaches its optimum thickness.

This relevant region may then be masked, for example, with lacquer, tape or clamping device. The unmasked regions of the substrate are then anodised further, to allow the anodised coating (usually an oxide layer) on the remainder of the substrate to reach its thicker, optimum value.

Alternatively, when it is desirable to leave the cylindrical region of the diaphragm uncoated, the relevant region of the substrate may be masked at the outset, prior to the anodising procedure.

Although simple masking techniques may be employed in the present invention, they can have their drawbacks. For example, when conventional masking tape is employed, some of the electrolyte from the cell may creep under the edges of the mask, causing at least part of the masked region to be anodised. Moreover, any electrolyte under the mask may overheat, damaging the mask itself. Thus, modifications may be made to the conventional masking techniques to ameliorate these disadvantages.

A pressurized fluid (such as air) may be pumped under a mechanical mask. Any leakage will therefore be of air, thus preventing electrolyte from seeping beneath the edges of the mask in the opposite direction. In this way, the region of the substrate (diaphragm) under the mask may be prevented from coming into contact with electrolyte, and thus, remains unanodised.

An auxiliary anode may be employed in conjunction with a mechanical mask. The auxiliary electrode is preferably selected such that the resistance between the electrolyte

and itself is less than the resistance between the substrate (diaphragm) and the electrolyte. As a result, current preferentially flows to the auxiliary anode, reducing the amount of anodising that occurs in the masked region of the substrate. Suitable materials for forming the auxiliary electrode include lead, carbon, and platinum, although other suitable materials are known in the art.

When it is desired to produce a tapered coating, the loudspeaker diaphragm may be anodised by:

providing an electrochemical cell comprising a cathode and an electrolyte,

connecting the loudspeaker diaphragm as the anode of the cell,

passing a current through the cell, such that an oxide layer is formed on the loudspeaker diaphragm, and

controlling the current density distribution within the cell, such that the oxide layer is formed more rapidly in one region of the diaphragm than in another region of the diaphragm.

The current density distribution of the cell may be controlled by operating the cell at current densities that are higher than those conventionally employed in anodising processes. For example, the cell may be operated at 5 amps per dm^2, preferably, from 10 to 200 amps per dm^2, more preferably, 60 to 150 amps per dm^2, most preferably, 80 to 100 amps per dm^2.

It is believed that by operating at current densities above those conventionally employed, the voltage drop within the electrolyte may be increased with respect to that at the

electrolyte/anode interface. For example, by providing a cell layout such that some areas of the anode are significantly closer to the cathode than others, it is possible to vary the effective impedances, and hence, the locally current densities. Since all areas experience the same anodising time, those having the highest local current densities will receive the thickest coating.

A mask may be placed between the cathode and the loudspeaker diaphragm to alter the current pathway between them. By varying the size, geometry and/or position of the mask relative to the diaphragm, the variation in thickness of the oxide layer may be controlled.

Preferably, a flow of electrolyte is passed over the surface of the loudspeaker diaphragm. Passing the electrolyte over the substrate in this manner, removes the heat generated by the oxidation process away from the surface of the diaphragm. The electrolyte may be pumped through a channel defined by the diaphragm and the mask.

Referring to Figure 10, there is provided an electrochemical cell 10, which is suitable for anodising a diaphragm, in accordance with the present invention. The cell 10 comprises a cathode 12, an anode 14 and a housing 16 containing an electrolyte of sulphuric acid.

In use, a diaphragm formed of an aluminium substrate (not shown) is coupled to the anode 14 of the cell 10. The electrolyte temperature is maintained at approximately 25 degrees C, and a current density of 1.5 Amps per square decimetre is applied to the diaphragm, causing a layer of

aluminium oxide to be deposited on the inner and outer surfaces of the substrate.

Once the anodically formed oxide layer in the neck region of the diaphragm reaches its optimum thickness for the neck region of the diaphragm, the diaphragm is removed from the cell 10. The neck portion of the diaphragm is then masked, and the anodising process is continued, to allow the anodically formed oxide layer on the remainder of the diaphragm to reach its thicker, optimum value. As a result, the thickness of the oxide layer in the remaining regions of the diaphragm is greater than that of the neck region.

Figure 11 is a schematic drawing of a first example of an arrangement that may be employed to mask a substrate. The substrate 20 is masked in the region "c" using a device 26. The device 26 includes a channel 28. In use, air pressure is applied through the channel 28. As a result, air is forced out between the mask and the workpiece 20 as shown by the arrows "d" at any point of imperfect contact between the device 26 and the workpiece 20. Thus, electrolyte is prevented from reaching the masked region "c". In this way, the anodically formed oxide layer is prevented from forming in the masked region "c". However, an oxide layer 24 is formed on the unmasked region of the substrate 20.

The arrangement described with reference to Figure 11 may be employed to mask a loudspeaker diaphragm substrate.

Figure 12 is a schematic drawing of a second example of an arrangement that may be employed to mask a substrate. As with Figure 11, the substrate 20 is masked in the region "c"

using a device 26. The device 26 comprises a channel 28, in which an auxiliary anode 30 is disposed. The auxiliary anode 30 may be formed of, for example, lead, graphite or platinum and the resistance between this auxiliary anode 30 and the electrolyte 22 is less than the resistance between the substrate 20 and the electrolyte 22. Thus, should the mask device 26 not make perfect contact with the substrate (work piece) 20, allowing leakage of electrolyte into the masked area "c" when current is passed through the cell 10, current preferentially flows to the auxiliary anode 30, reducing the amount of anodising that occurs in the masked region "c" of the substrate 20. An oxide layer 24, however, forms on the unmasked region of the substrate 20.

The arrangement described with reference to Figure 12 may be employed to mask a loudspeaker diaphragm substrate.

Referring to Figure 13, there is provided an electrochemical cell 110, which may be employed to produce a loudspeaker diaphragm in accordance with the present invention. The cell 110 comprises a casing 112, a cathode 114 an inlet 116 and an outlet 118. A loudspeaker diaphragm 120, is employed as the anode of the cell 110. The cell 110 is provided with an electrolyte 122 of sulphuric acid. Masks 124 are positioned in spaced relation to the diaphragm 120. The diaphragm 120 and the cathode 114 are both formed of aluminium.

In operation, the electrolyte 122 is pumped through the cell 110 via the inlet 116 and outlet 118. The electrolyte flows through channels defined by the masks 124 and the diaphragm 120, as shown by the arrows "a". In this way, a flow of

electrolyte 122 is passed over both the inner and outer surfaces of the diaphragm 120.

When a current is passed through the cell 110, an anodised oxide layer is formed on the surface of the diaphragm 120. The cell 110 may be operated at a current density of 90 amps per dm^2. At this current density, there is a significant voltage drop within the electrolyte and across the diaphragm 120. Thus, the effective voltage tapers from a maximum at the outer periphery 120b of the diaphragm 120 to a minimum at the neck region 120a of the diaphragm 120. The local current density also tapers accordingly. Thus, thickness of the oxide layer varies from a maximum at the outer periphery 120b of the diaphragm 120 to a minimum at the neck region 120a of the diaphragm 120.

This taper in the thickness of the oxide layer is shown in further detail in Figure 14. As shown in the drawing, the loudspeaker diaphragm 120 has a neck region 120a, and a conical region 120c. The loudspeaker diaphragm 120 is provided with an oxide layer 120d. The oxide layer 120d is thinner in the neck region 120a of the diaphragm 120 than at the outer periphery 120b of the diaphragm 120. In fact, the oxide layer 120d is approximately 2 microns thick in the neck region 120a, and the start of the conical region 120e of the diaphragm 120. The oxide layer 120d in the conical region 120c, however, tapers to a maximum value of approximately 10 microns at the outer periphery 120b of the diaphragm 120.

The thickness of the aluminium substrate in the conical region 120c of the diaphragm 120 may be tapered in reverse

as exemplarily shown in Figure 6, from a minimum value of 0.11 mm at the outer periphery 120b of the diaphragm 120 to a maximum value of 0.118 mm at the start of the conical region 120c. This reverse taper is formed as a result of the anodising process. When a metal (e.g. aluminium) diaphragm is anodised, some of the metal at the surface of the diaphragm is consumed to form the anodically formed oxide layer. Thus, the metal diaphragm becomes thinner in the regions where the anodically formed oxide layer is applied.

Claims

1. A loudspeaker diaphragm comprising a first region and a second region, said diaphragm having a coating on at least part of said first region and an optional coating on at least part of said second region,

wherein at least part of the coating on said first region is thicker than at least part of the optional coating on said second region of the diaphragm.

2. A loudspeaker diaphragm as claimed in Claim 1, wherein at least a part of said first region forms at least a part of the acoustic region of the diaphragm.

3. A loudspeaker diaphragm as claimed in Claim 1 or 2 wherein said first region is arranged radially outside of said second region.

4. A loudspeaker diaphragm as claimed in any preceding claim, wherein said first region is substantially conical in shape.

5. A loudspeaker diaphragm as claimed in any preceding claim, wherein said first region is substantially identical to said acoustic region of said diaphragm.

6. A loudspeaker diaphragm as claimed in any preceding claim, wherein said second region is substantially cylindrical in shape.

7. A loudspeaker diaphragm as claimed in any preceding claim, wherein said second region is adjacent to the inner edge of said first region.

8. A loudspeaker diaphragm as claimed in any preceding claim, which is a loudspeaker cone.

9. A loudspeaker diaphragm as claimed in any preceding claim, wherein the coating on the first region covers the region between the area of attachment of a loudspeaker voice coil and the periphery of the diaphragm.

10. A loudspeaker diaphragm as claimed in any one of claims 1 to 8, wherein the coating on the first region covers the region between the area of attachment of a loudspeaker dome and the periphery of the diaphragm.

11. A loudspeaker diaphragm as claimed in any preceding claim, wherein the entire coating on said first region is thicker than the entire optional coating on the second region of the diaphragm.

12. A loudspeaker diaphragm as claimed in any preceding claim, which comprises a coating on the second region of the diaphragm.

13. A loudspeaker diaphragm as claimed in claim 12, wherein the coating on the second region is formed of the same material as the coating on the first region of the diaphragm.

14. A loudspeaker diaphragm as claimed in any preceding claim, wherein the coating is tapered from a minimum value in the second region of the diaphragm to a maximum value in the first region of the diaphragm.

15. A loudspeaker diaphragm as claimed in claim 14, wherein the coating in the second region is itself tapered.

16. A loudspeaker diaphragm as claimed in claim 14, wherein the coating in the second region is substantially uniform in thickness.

17. A loudspeaker diaphragm as claimed in any one of claims 1 to 13, wherein the coating on the first region of the diaphragm is substantially uniform in thickness.

18. A loudspeaker diaphragm as claimed in claim 17, wherein the second region of the diaphragm is provided with a coating of substantially uniform thickness that is thinner than the coating on the first region of the diaphragm.

19. A loudspeaker diaphragm as claimed in any preceding claim, wherein the loudspeaker diaphragm is at least partially formed of aluminium, titanium, and/or magnesium or an alloy comprising at least one of aluminium, titanium, and magnesium.

20. A loudspeaker diaphragm as claimed in claim 19, wherein at least a part of the coating is formed of a carbide, boride, nitride or oxide.

21. A loudspeaker diaphragm as claimed in claim 20, wherein at least a part of the coating is formed of an anodically formed oxide layer.

22. A loudspeaker diaphragm as claimed in claim 21, wherein the anodically formed oxide layer has a thickness of 0.1 to 8 microns in the second region of the diaphragm, and a thickness of 2 to 50 microns in the first region of the diaphragm.

23. A loudspeaker diaphragm as claimed in any preceding claim, wherein at least part of the outer surface of the diaphragm is coated, and wherein at least part of the inner surface of the diaphragm is coated.

24. A loudspeaker diaphragm as claimed in claim 23, wherein the coating on the inner surface of the diaphragm is thicker in the first region of the diaphragm than in the second region of the diaphragm.

25. A loudspeaker diaphragm as claimed in claim 23, wherein the coating on the inner surface of the diaphragm extends across at least a part of the first region of the diaphragm and is absent from the second region of the diaphragm.

26. A loudspeaker diaphragm as claimed in any one of claims 1 to 22, wherein the coating is only present on one surface of the diaphragm.

27. A loudspeaker diaphragm as claimed in claim 26, wherein the coating is located on the inner surface of the first

region of the diaphragm and optionally on the second region of the diaphragm.

28. A method for producing a loudspeaker diaphragm, said method comprising:

providing a loudspeaker diaphragm comprising a first region and a second region region,

applying a coating to at least part of said first region,

optionally applying a coating to at least part of the second region, such that at least part of the coating on the first region is thicker than at least part of the optional coating on the second region of the diaphragm.

29. A method for producing a loudspeaker diaphragm as claimed in claim 28, wherein at least a part of said first region forms at least a part of the acoustic region of the diaphragm.

30. A method for producing a loudspeaker diaphragm as claimed in claim 28 or 29, wherein said first region is arranged radially outside of said second region.

31. A method for producing a loudspeaker diaphragm as claimed in any one of claims 28 to 31, wherein said first region is substantially conical in shape.

32. A method for producing a loudspeaker diaphragm as claimed in any one of claims 28 to 31, wherein said first region is substantially identical to said acoustic region of said loudspeaker diaphragm.

33. A method for producing a loudspeaker diaphragm as claimed in any one of claims 28 to 32, wherein said second region is substantially cylindrical in shape.

34. A method for producing a loudspeaker diaphragm as claimed in any one of claims 28 to 33, wherein said second region is adjacent to the inner edge of said first region.

35. A method as claimed in any one of claims 28 to 34, wherein the coating on the first region and the optional coating on the second region are formed by anodising the diaphragm.

36. A method as claimed in claim 35, which comprises the steps of:

applying a mask to at least a part of the second region of the diaphragm,

providing an electrochemical cell comprising a cathode, and an electrolyte;

connecting the masked diaphragm as the anode of the cell; and

passing a current through the cell to cause the coating to form on the unmasked regions of the diaphragm.

37. A method as claimed in claim 36, wherein the mask is applied before any coating is applied to the diaphragm.

38. A method as claimed in claim 36, which comprises:

anodising the diaphragm prior to masking, such that the coating on the diaphragm reaches a certain thickness;

masking at least part of the second region of the diaphragm; and

anodising the masked diaphragm further.

39. A method as claimed in any one of claims 36 to 38, wherein the whole of the second region of the diaphragm is masked.

40. A method as claimed in any one of claims 36 to 39, wherein a pressurised fluid is pumped underneath the mask to prevent electrolyte from seeping under the mask in the opposite direction.

41. A method as claimed in any one of claims 36 to 39, which further comprises the steps of:

providing the cell with an auxiliary anode, wherein said auxiliary anode is selected such that the resistance between the electrolyte and the auxiliary anode is less than the resistance between the substrate and the electrolyte; and

connecting the auxiliary anode to the cathode of the cell.

42. A method as claimed in claim 41, wherein the auxiliary electrode is formed of at least one of lead, carbon, and platinum.

43. A loudspeaker comprising a diaphragm as claimed in any one of claims 1 to 27.

44. A loudspeaker comprising a diaphragm formed by a method as claimed in any one of claims 28 to 42.

45. A loudspeaker diaphragm as herein described, and with reference to the accompanying drawings.

46. A method as herein described, and with reference to the accompanying drawings.

FIG. 1.

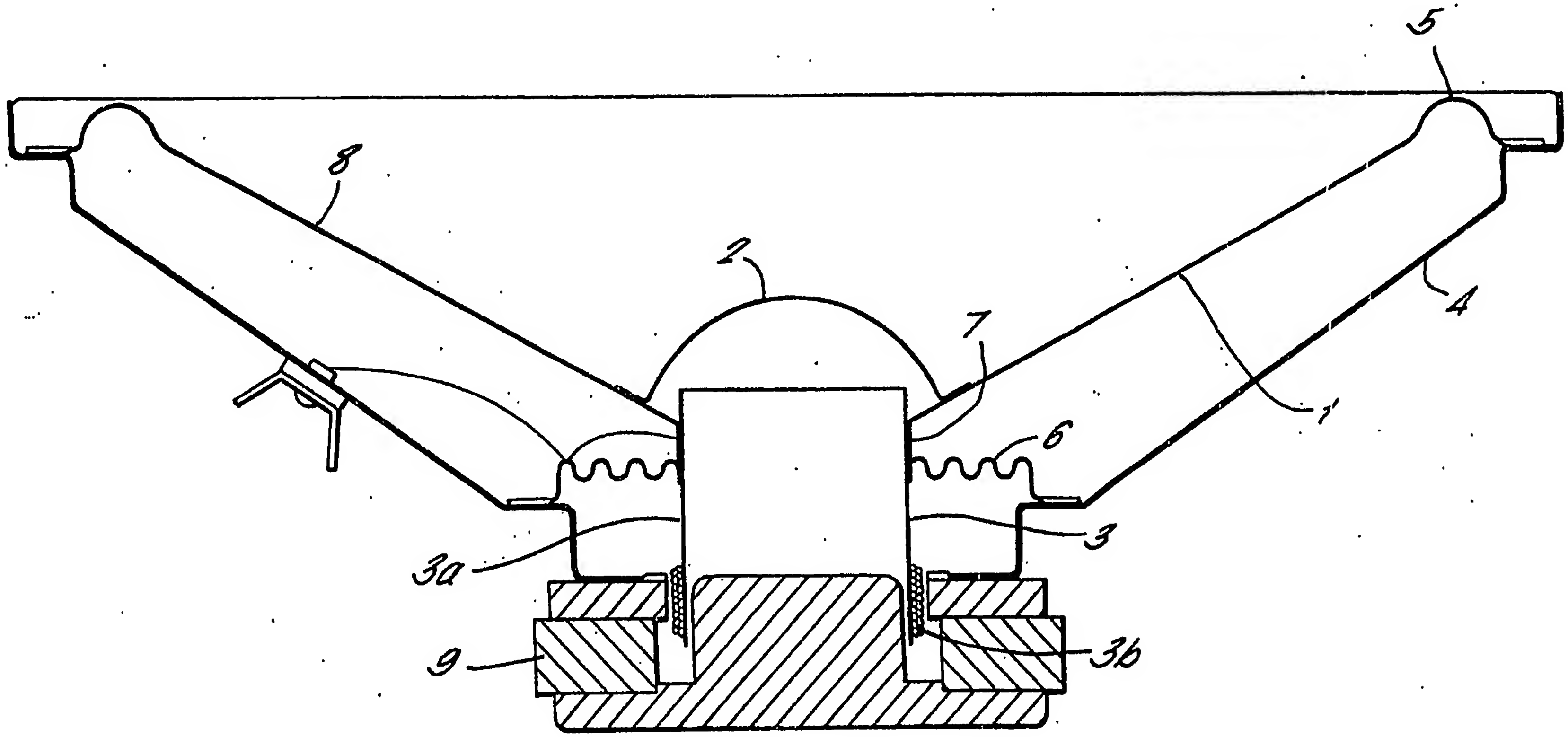

FIG. 2.

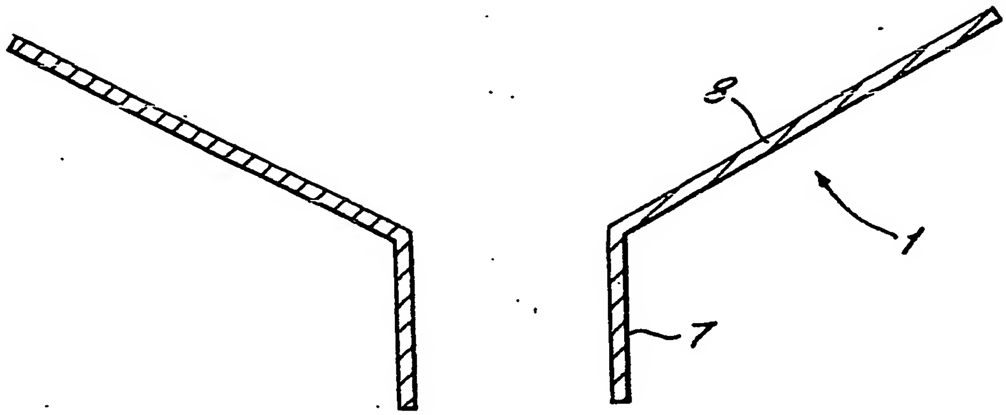

FIG. 3.

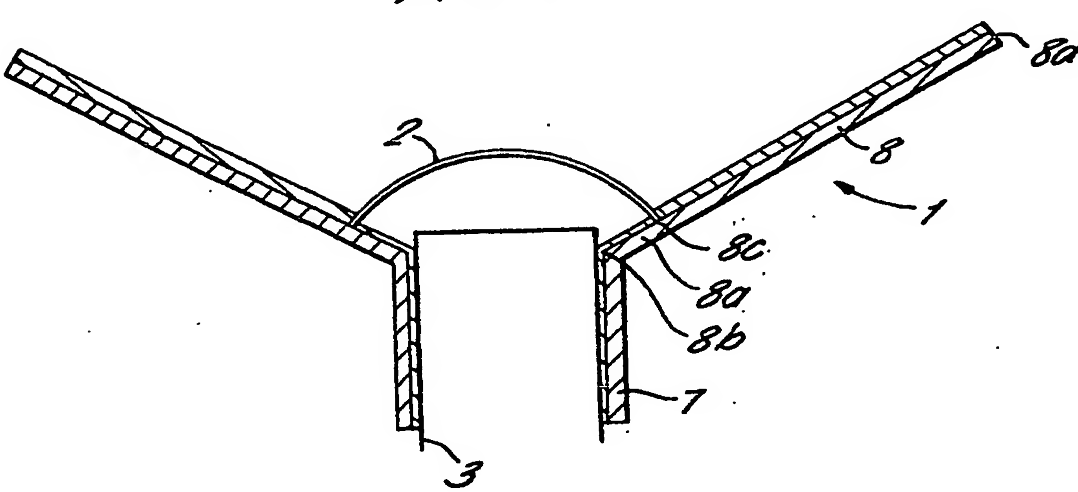

FIG. 4.

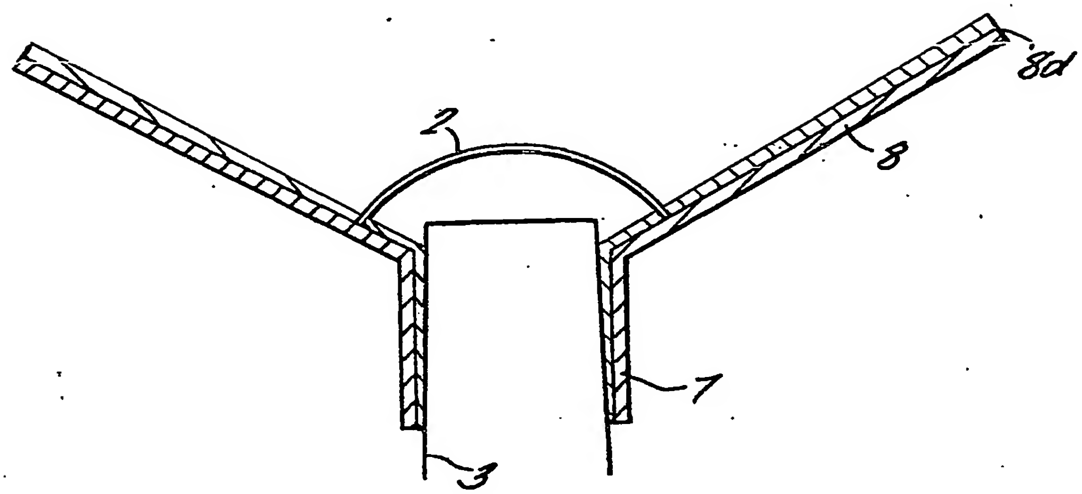

FIG. 5.

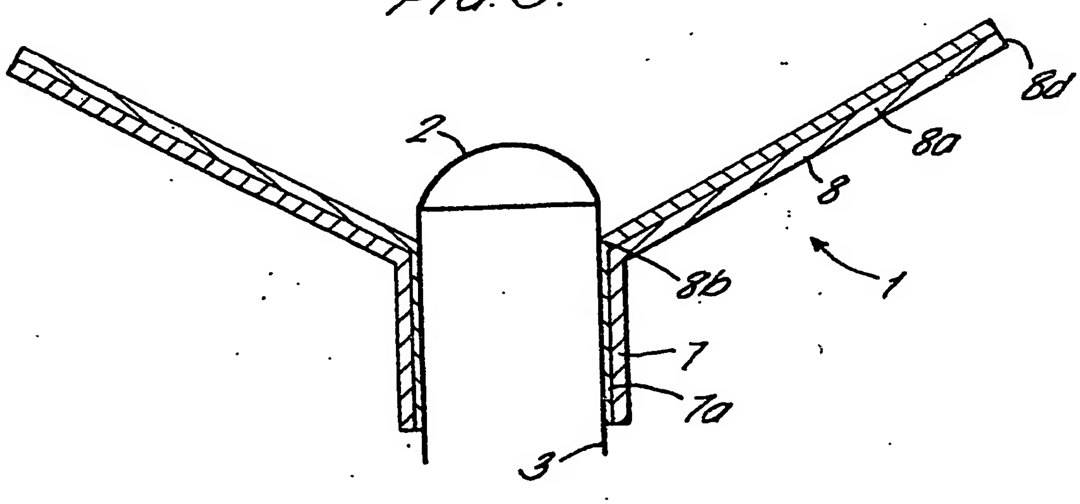

FIG. 6a.

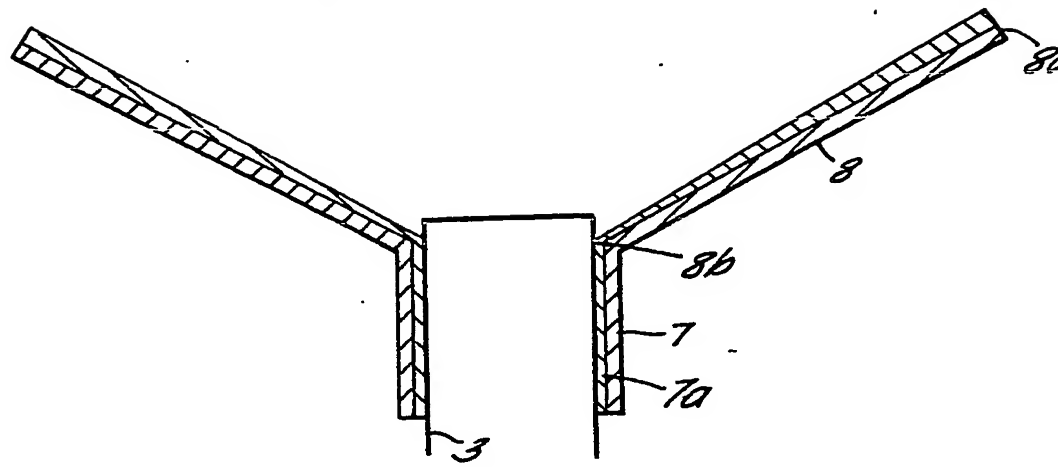

FIG. 6b.

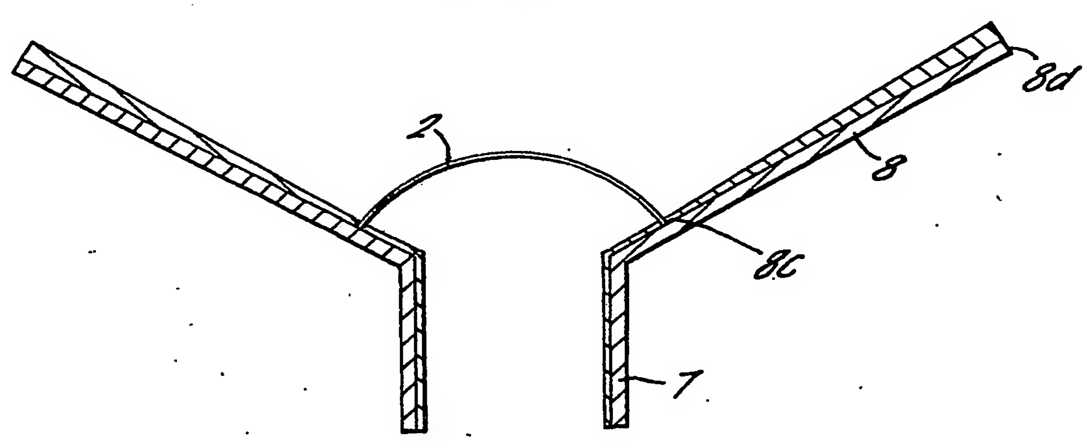

FIG. 7.

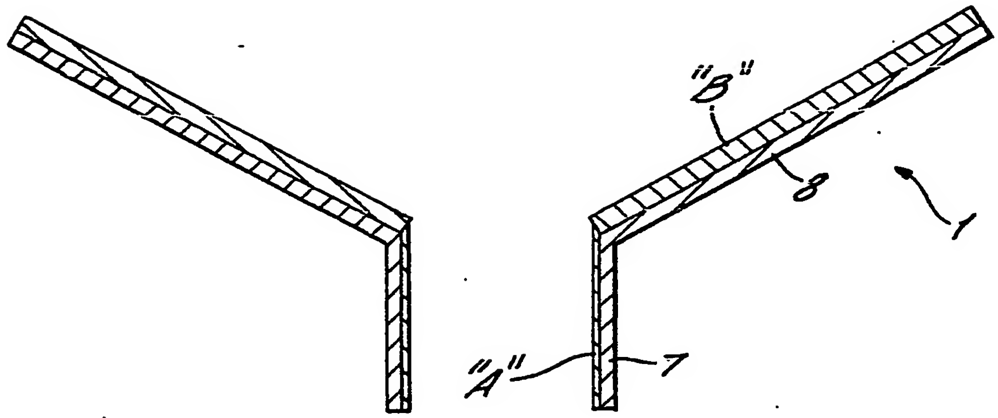

FIG. 8.

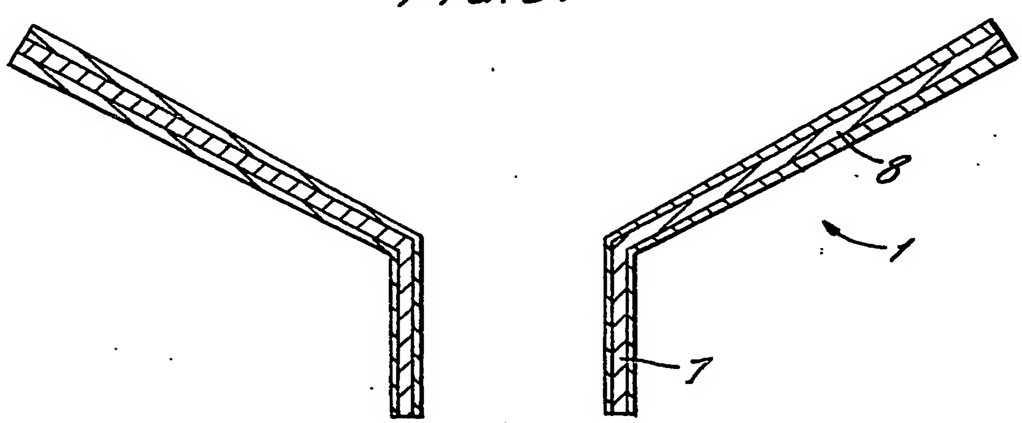

FIG. 9.

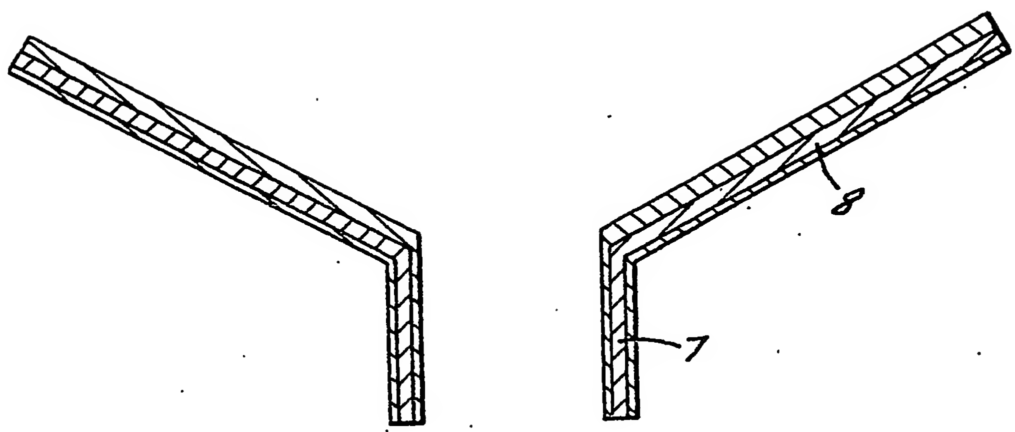

FIG. 10.

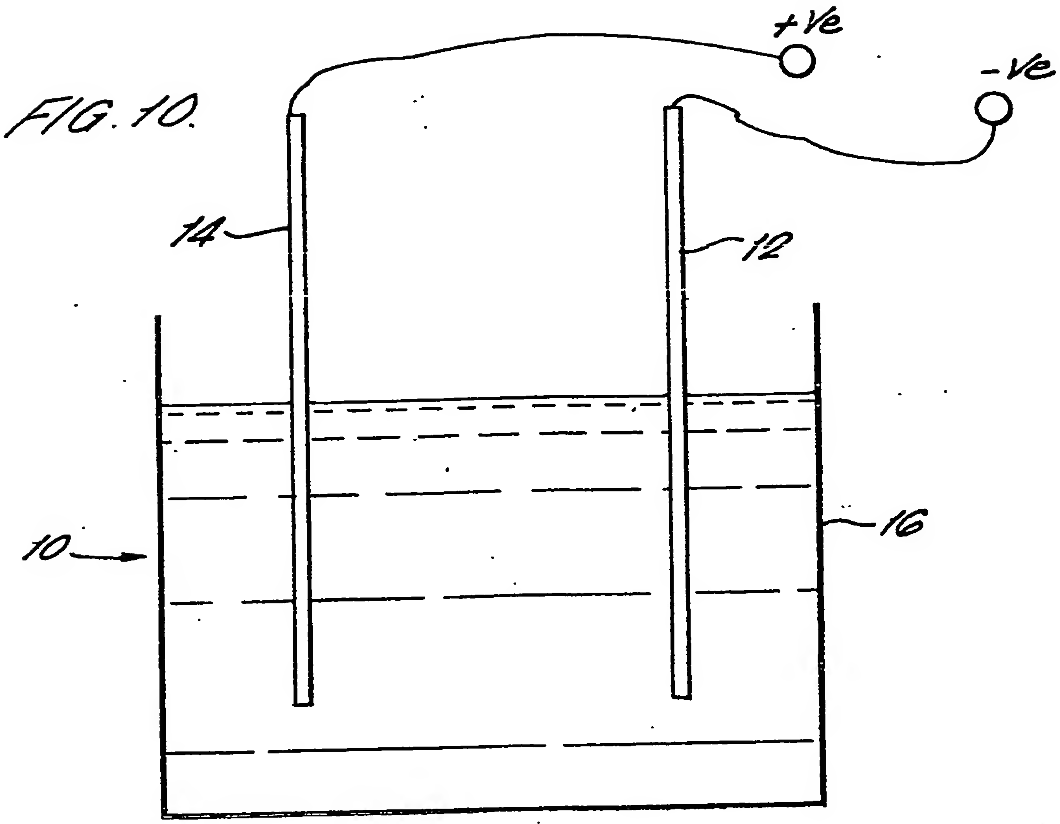

FIG. 11.

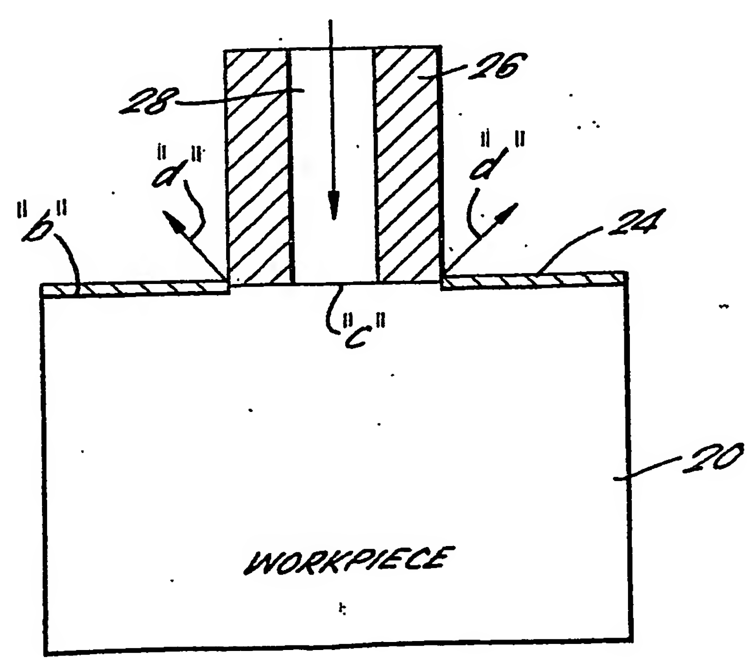

FIG. 12.

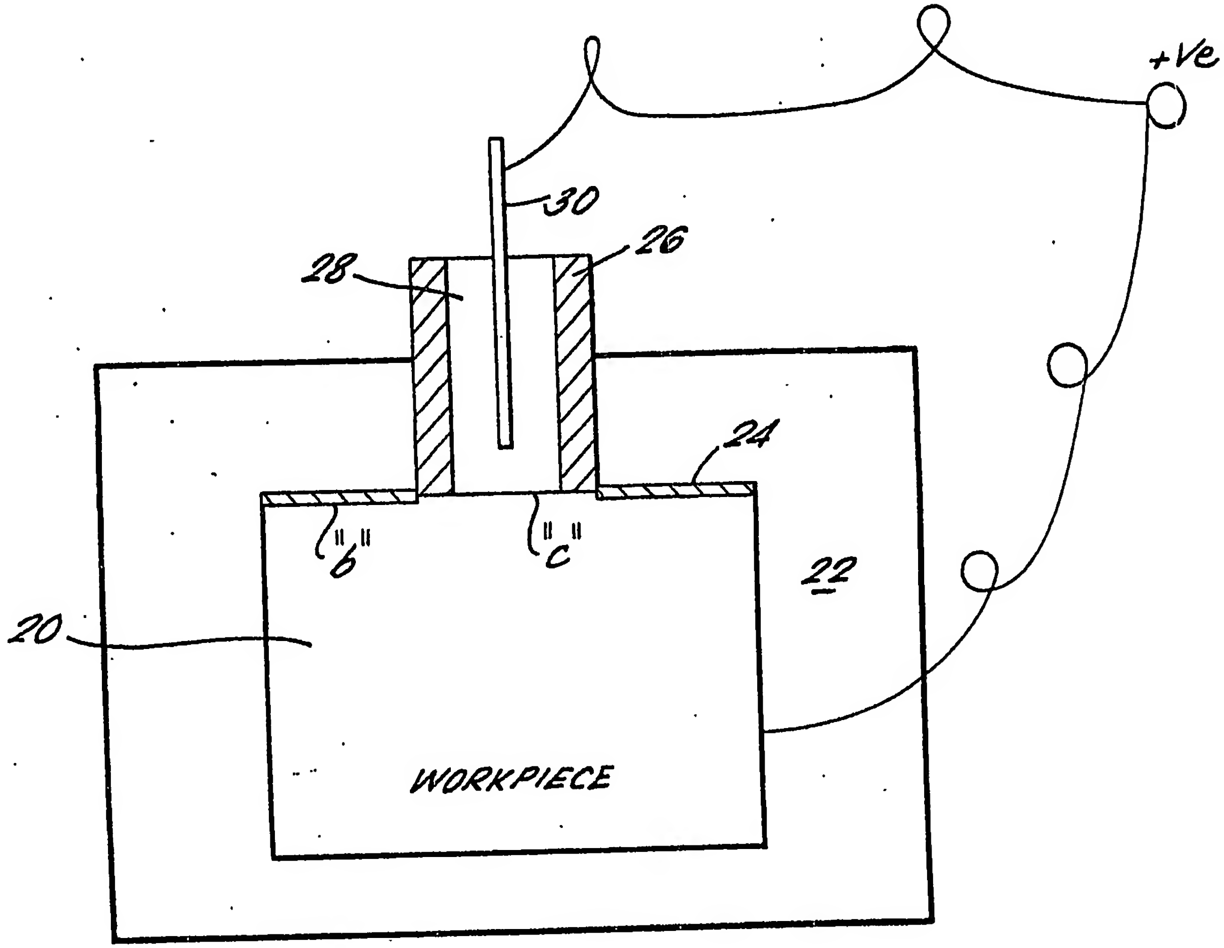

FIG. 13.

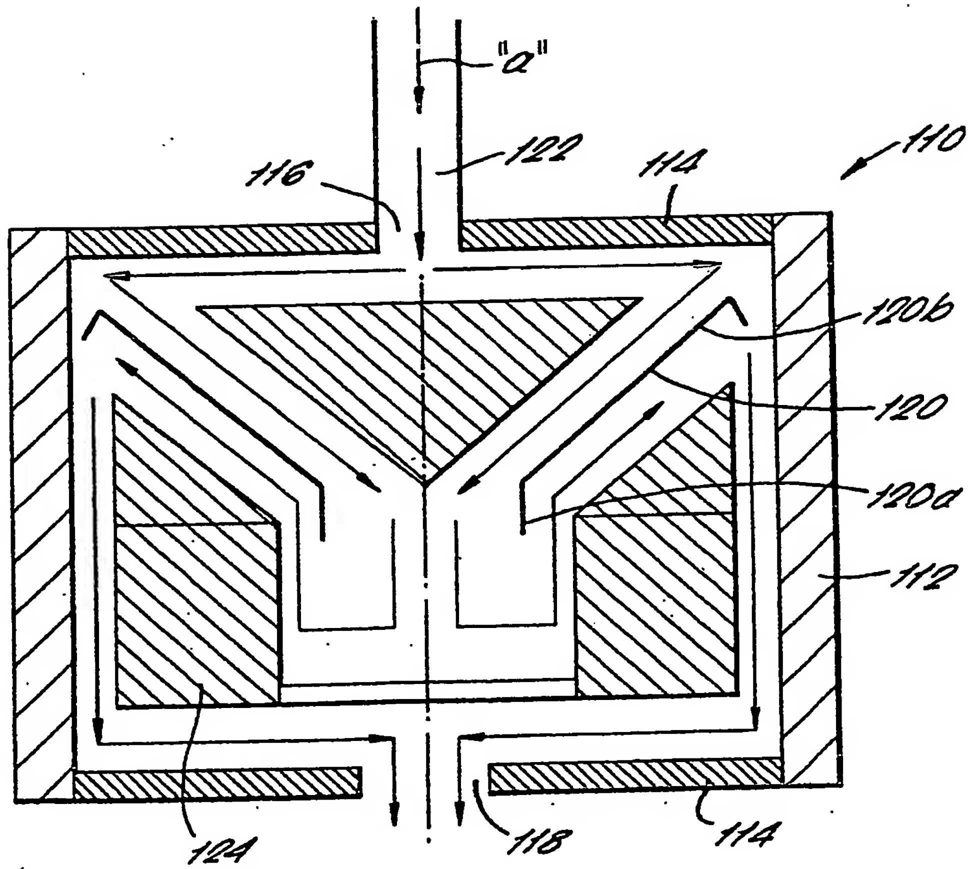

FIG. 14.